Comparison of the Convective Downdrafts Observed in MC3E and TC4

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1. Motivation

The microwave polarization data of GMI (Global Precipitation Measurement Microwave Imager), especially at high frequencies, provide information on cloud anvils. Hence, the GMI data can be used to study the factors that impact cloud anvil.

The ice crystal concentration (ICC) in the mixed-phase region is an important factor that impacts cloud anvil (Zeng et al. 2011, 2013). It is influenced by convective downdrafts. In this study, the effect of convective downdrafts on ICC is studied, using Doppler radar data from two field campaigns: MC3E (Mid-latitude Continental Convective Clouds Experiment) and TC4 (Tropical Composition, Cloud and Climate Coupling Experiment).

2. Effect of Downdrafts on ICC

ICC is connected to ice nuclei (IN) via the ice crystal enhancement (IE) factor μ, or

$$ICC = \mu \times IN$$

where μ varies from 1 to 10^4 due to the Hallett-Mossop mechanism, convective downdrafts and other ice multiplication processes.

Convective downdrafts impact μ greatly, which is illustrated in Fig. 1 using two air parcels. The ICC in the left parcel with a vertical circulation is larger than that in the stationary one, implying that $\mu > 1$ in the left one. Figure 2 displays μ versus the vertical displacement with different IN formulas and microphysics.

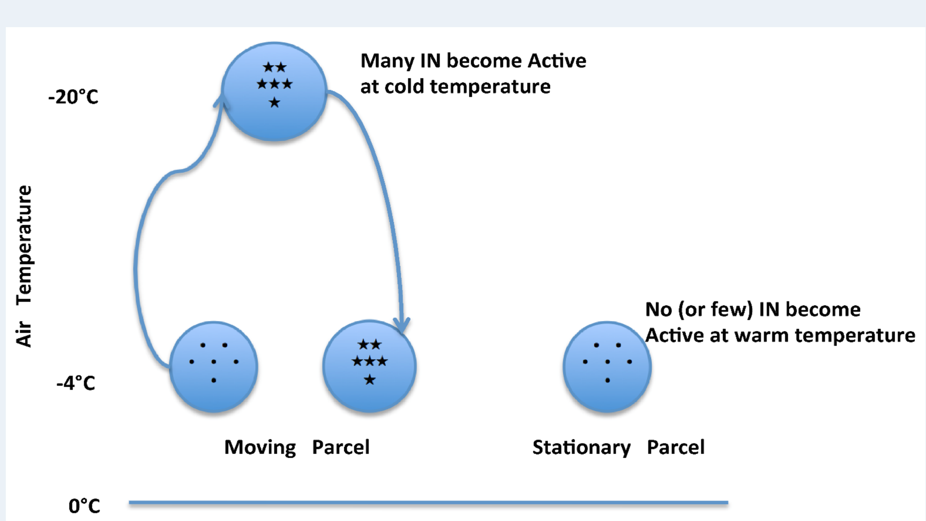


Fig. 1 Schematic showing the effect of vertical circulation (or downdraft) on the ICC via two air parcels with liquid droplets. The left air parcel first rises adiabatically from one level (e.g., -4℃) to another (e.g., -20℃) with new ice particles forming before returning to its original level with the new ice particles. The right one is stationary such that no super-cooled droplets become ice crystals.

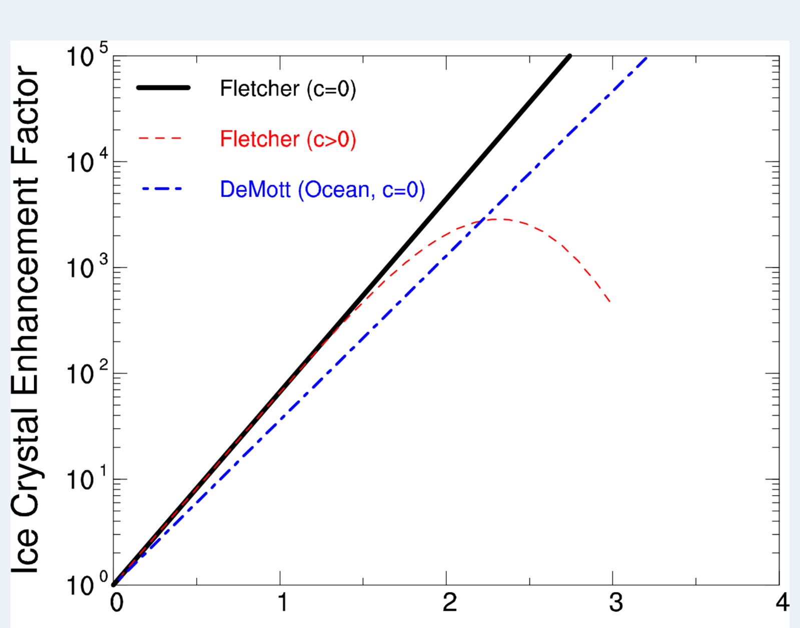
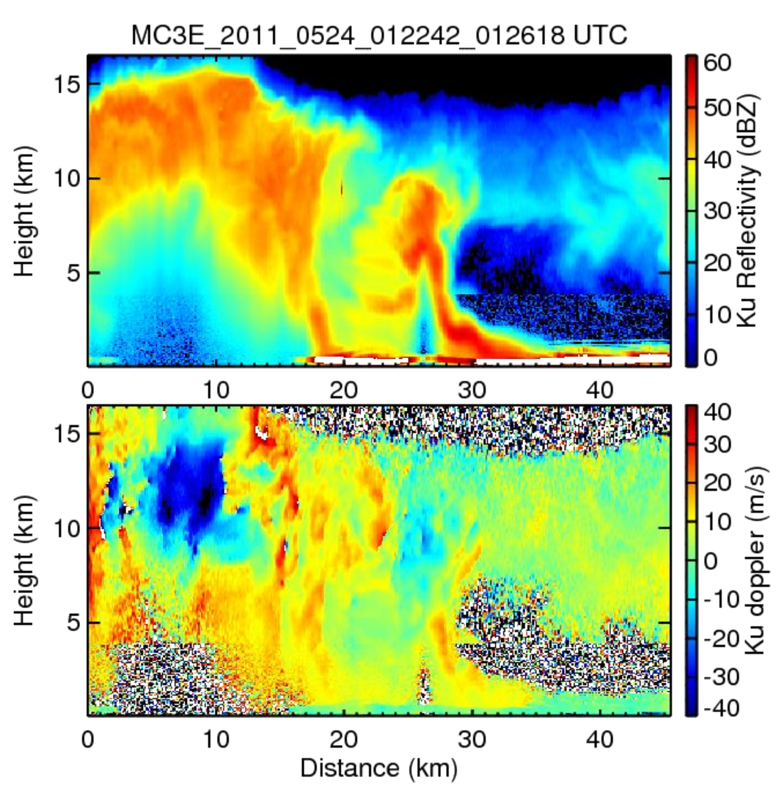


Fig. 2 Schematic showing the IE factor μ versus Δz the vertical displacement of thermal (or scale of horizontal vortex ring). The black and blue lines are obtained with the IN formulas of Fletcher (1962) and DeMott et al. (2016), respectively. The red line represents the descending air parcel with ice crystal removal (c>0). The red line deviates from the black one because c (the percentage of ice crystals removed) increases with Δz.

3. Downdraft Observations during MC3E

Doppler radars on the NASA high-altitude (~20 km) ER-2 aircraft provide unique information on downdrafts especially in the mixed-phase region (Heymsfield et al. 2010, 2013). Figure 3, for example, displays the vertical cross section of radar reflectivity and Doppler velocity of a mesoscale convective system (MCS) observed during MC3E.



The figure shows that convective updrafts are concentrated at the storm center while downdrafts arise away from the center.

Fig. 3 Vertical cross section along the flight track from 1222-0126 UTC 24 May 2011 during MC3E, for radar reflectivity (top) and Doppler velocity (bottom) that are obtained from the dual-frequency Doppler radar at Ku band.

4. Downdraft Observations during TC4

Airborne Doppler radars also provide downdraft observations in the Tropics for comparison. Figure 4, for example, displays the vertical cross section of radar reflectivity and Doppler velocity of an MCS observed during TC4 (Tropical Composition, Cloud and Climate Coupling Experiment).

The vertical cross section (or the flight track) is parallel to the squall line and behind the convective line. The figure shows that convective downdrafts alternate with updrafts in the mixed-phase region. Such side-by-side alternation of up- and down-drafts in the mixed-phase region is different from the draft pattern in Fig. 3. It can increase ICC significantly based on Figs. 1 and 2.

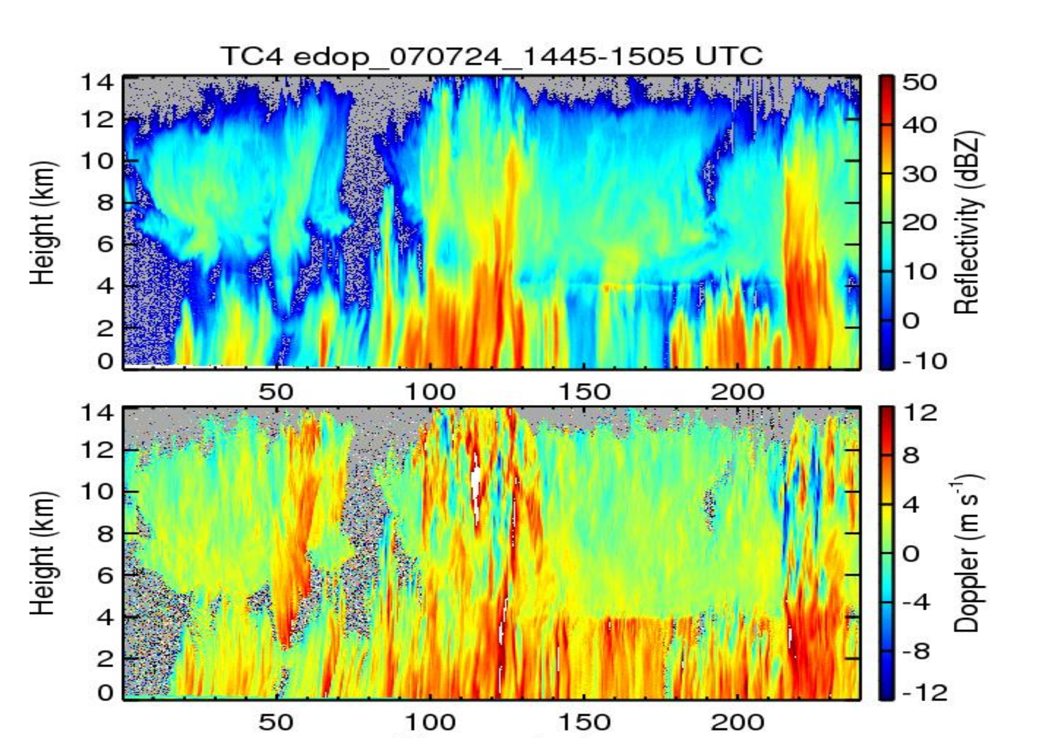


Fig. 4 Vertical cross section along the flight track from 1445-1505 UTC 24 July 2007, for radar reflectivity (top) and Doppler velocity (bottom) that are obtained from EDOP (ER-2 Doppler radar) observations during TC4. In the bottom pane, red and blue represent downward and upward motions, respectively.

5. Analysis of Downdraft Dynamics

A tropical MCS with in situ sounding data was analyzed for downdraft dynamics. Fig. 5 displays its vertical cross sections of radar reflectivity and Doppler velocity. Fig. 6 (left) also displays in situ sounding data for buoyancy analysis.

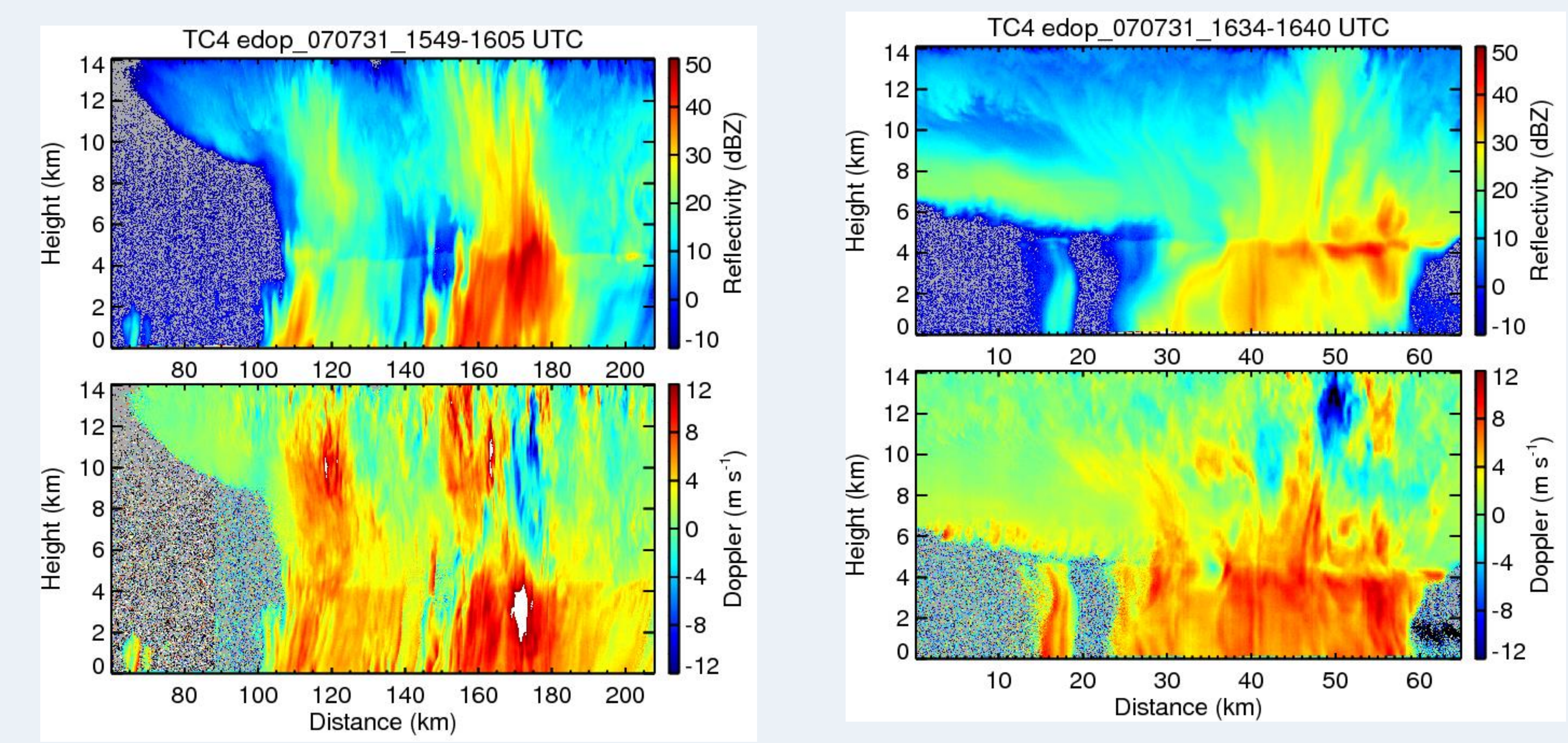


Fig. 5 Vertical cross sections of radar reflectivity (top) and Doppler velocity (bottom) along (1) the EDOP flight track that is parallel to the leading edge of the MCS (left, from 1549-1605 UTC 31 July 2007), and (2) the flight track that is perpendicular to the leading edge (right, from 1634-1640 UTC).

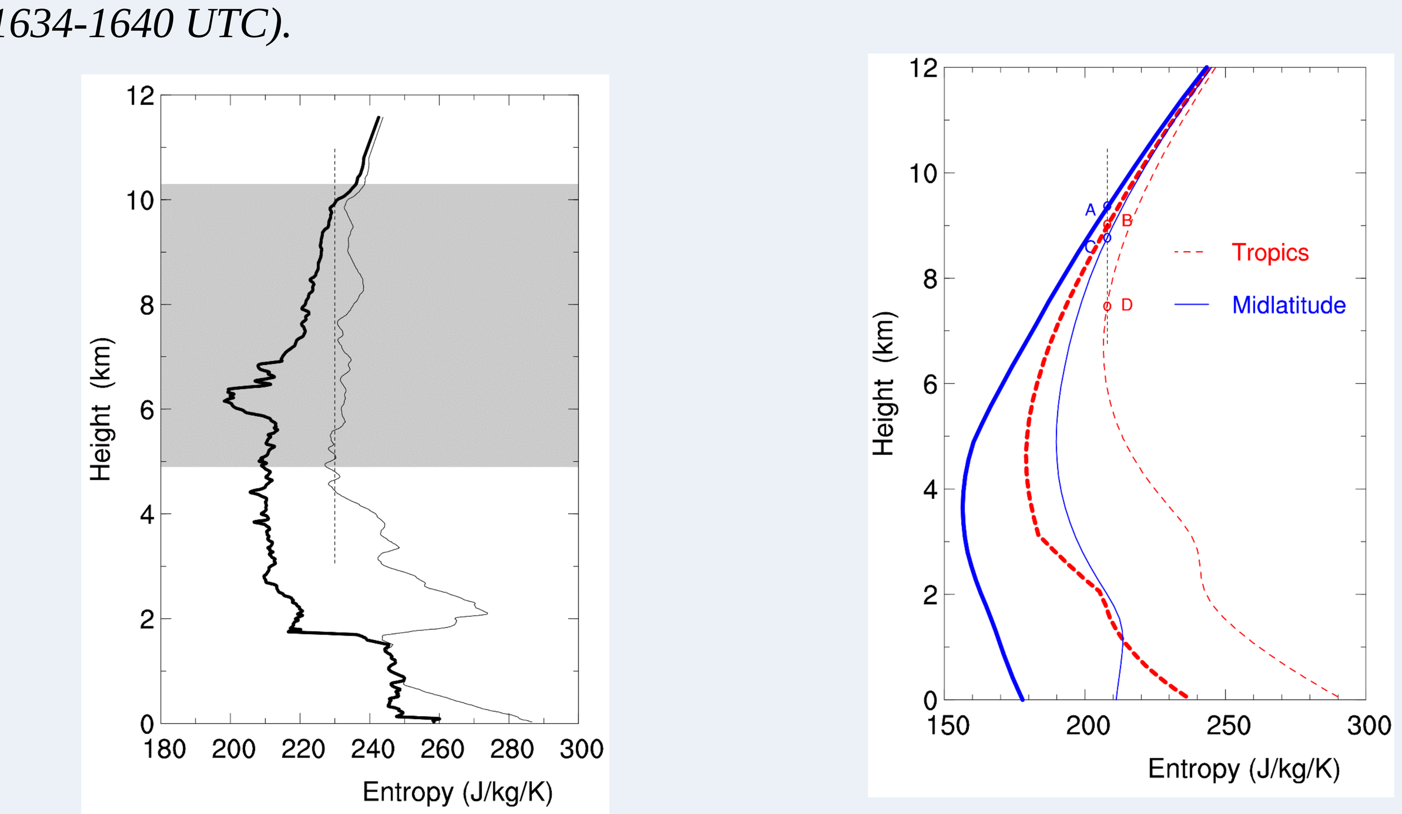


Fig. 6 (Left) vertical profiles of moist entropy (thick) and saturation moist entropy (thin line) from the in situ sounding relevant to the MCS in Fig. 5, where the vertical dashed line shows the buoyancy of a mixed air parcel and the shading indicates the mixed-phase region. (Right) Same as the left figure except for mean sounding data of Tropics (red) and mid-latitudes (blue), showing that a mixed air parcel may descend from point B to D in a tropical cloud whereas a similar parcel from A to C in an mid-latitudinal cloud.

6. Conclusions

- Doppler radar observations revealed a side-by-side alternation of up- and down-drafts in the mixed-phase region.
- Mixing between cloud air parcels and their environment provides energy for downdrafts.
- Difference in sounding profile between the Tropics and mid-latitudes explains the difference in draft pattern between MC3E and TC4.

This research was supported by the NASA Precipitation Measurement Mission (PMM) project under grant NNX16AE24G. Dr. Tian was also supported by the PMM and the Remote Sensing Theory projects.